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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : G01F 1/74, B63C 11/24 A61M 16/00

A1

(11) International Publication Number: WO 91/06832

(43) International Publication Date: 16 May 1991 (16.05.91)

(21) International Application Number: PCT/NO90/00161

(22) International Filing Date: 30 October 1990 (30.10.90)

(30) Priority data: 8924469.3 31 October 1989 (31.10.89) GB

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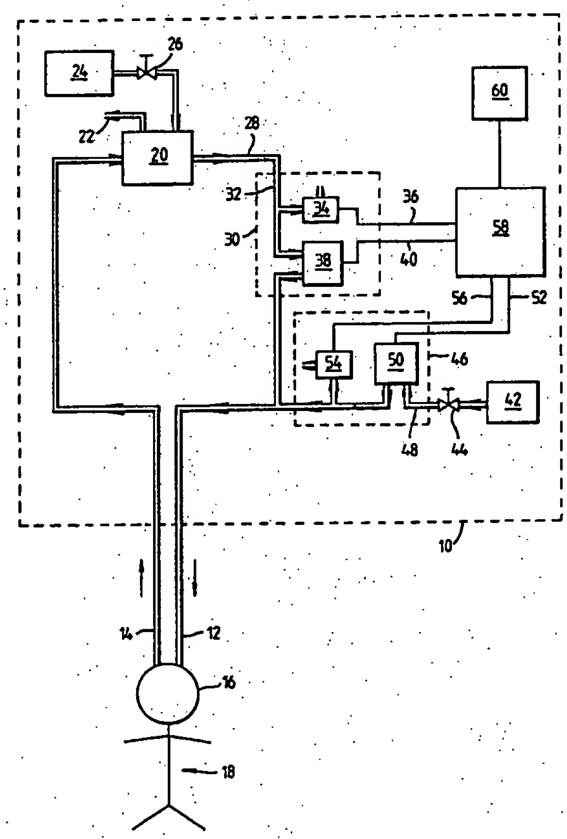
(81) Designated States: AT, AT (European patent), AU, BE (European patent), BF (OAPI patent), BJ (OAPI patent), BR, CA, CF (OAPI patent), CG (OAPI patent), CH (European patent), CM (OAPI patent), DE, DE (European patent), DK, DK (European patent), ES, ES (European patent), FI, FR (European patent), GA (OAPI patent), GB, GB (European patent), GR (European patent), HU, IT (European patent), JP, KP, KR, LU (European patent), MC, ML (OAPI patent), MR (OAPI patent), NL, NL (European patent), NO, SE, SE (European patent), SN (OAPI patent), SU, TD (OAPI patent), TG (OAPI patent), US.

Published
With international search report.

(54) Title: A GAS FLOW MEASURING SYSTEM

(57) Abstract

A gas flow measuring system comprising a gas flow conduit for carrying a gas mixture of known constituents in unknown proportions, a gas analyser (34) coupled to the conduit and generating analogue signals representative of the unknown proportions of the gas mixture, and a mass flow meter (38) coupled to the conduit and generating an analogue signal representative of the mass flow rate of the gas mixture. Further, the system includes a converter (108) for conversion of said analogue signals to digital signals, a digital processor for processing the digital signals from the converter, for producing output data of interest, such as volumetric flow rate of the gas mixture, a display means (60) for graphically and numerically displaying output data from the processor (58) in real time, and a storage means for long term storage of output data from the processor in a format which can be processed at a later time.



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A gas flow measuring system

The invention relates to a gas flow measuring system comprising a gas flow conduit for carrying a gas mixture of known constituents in unknown proportions, a gas analyser coupled to the conduit and generating analogue signals representative of the unknown proportions of the gas mixture, a mass flow meter coupled to the conduit and generating an analogue signal representative of the mass flow rate of the gas mixture, and a means for processing said signals to produce at least a signal representative of the volumetric flow rate of the gas mixture.

A system of the above-mentioned type is known from the published European patent application EP-A-0 274 868.

As also mentioned in the above-mentioned application, there are circumstances where it is desirable or essential to know instantaneous, short and long term volumetric gas flow rates, and preferably also the total volume of gas transferred in the longer term or in a certain period of time. For example, the monitoring of breathing gas mixture consumption rates in life support systems can give indications of metabolic rates and system leaks, while a measurement of total volumetric gas flow can be employed for determining overall efficiency and total cost of consumed gas.

Inspection, maintenance and repair operations in the offshore oil industry may require divers to operate for extended periods of time in water of great depth. For well known reasons, divers working at great depth and correspondingly great pressure cannot breathe ordinary air. Consequently, such divers must be supplied with a mixture comprising helium and oxygen, the correct percentage of oxygen being a function of the required pressure in the diver's helmet. Helium and oxygen of the necessary purity and in the substantial amounts needed for diving operations (including preceding preparation of the diver and succeeding depressurization) are very expensive. The helium consumption is minimized by supplying the diver through a closed loop breathing system in which the exhaled gases are passed through a purification system which removes carbon dioxide (and also most of the other undesirable gases and vapours, such as nitrogen and argon), and replaces oxygen depleted by breathing, while leaving the helium content theoretically intact.

In the known closed loop breathing systems the retention of helium is almost inevitably less than desired. Loss of helium also occurs through leakage, which will be exacerbated by the hyperbaric operating pressures. With high recovery rates in modern purification systems, the only significant (by molecular weight) remaining cotaminant will normally be nitrogen.

As already mentioned, the correct proportion of oxygen in the breathing gas mixture is not fixed, but is a function of the operational depth. Further complications in maintenance of the correct proportions of individual gases arise from the injection of make-up gases usually in the form of oxygen or a mixture of helium and oxygen, to compensate for leaks and for any necessary increase in system pressure.

It is therefore highly desirable, for reasons including health and safety, to know the instantaneous proportions and volumetric flow rates of the gas mixture supplied to and returned from the diver, the input and output of the regenerator or purification system, and the system make-up gases, both during full depth work by the diver and when the diver is in the diving bell or other saturation chamber system where the diver is purged of nitrogen prior to diving and controllably depressurized after diving. It is also highly desirable, for reasons including efficiency, monitoring and cost control, to know the total volumetric flows that have occurred over the entire diving operation (or any distinct stage of the diving operation), since these flow totals can give indications of the efficiency of various parts of the system and the financial costs of the gases. It is also clearly desirable to have an accurate measure of the total volume of bulk gases delivered by a gas manufacturer/supplier to the gas user (in a manner corresponding to the measuring of bulk supplies of liquid fuels).

The known system mentioned in the introduction has been found to have some weaknesses and deficiencies with respect to effective monitoring and operation of closed loop breathing systems for diving operations. Thus, the known system is only suitable for use in connection with a binary gas mixture, i.e. a mixture of only two gases, for instance oxygen and helium. Consequently, it is inaccurate for dive applications, since it only measures the proportion of one gas and derives the propor-

tion of the balance, the balance being supposed to consist of a single gas (e.g. helium). In practice, however, there may be up to 2% nitrogen in the dive gas, even after it has been through the recovery system. As the density of nitrogen is many times that of helium the resulting inaccuracies are significant. Another deficiency of the known system is that, in practice, it is not capable of calculating or determining actual flow rate.

It is an object of the inventon to provide a gas flow measuring system enabling efficient monitoring and optimal operation in that it can produce desired operational data which can be displayed in real time, and which in addition may be stored with a view to subsequent processing and utilization for later operations.

Another object of the invention is to provide such a system which is capable of determining actual flow rate.

A further object of the invention is to provide such a system which is suitable for monitoring of a ternary gas mixture, e.g. a mixture consisting of helium, oxygen and nitrogen.

The above objects are achieved with a system of the type stated in the introduction which, according to the invention, is characterized in that it includes a converter for conversion of said analogue signals to digital signals, a digital processor for processing the digital signals from the converter, to produce output data representative of, i.a., said volumetric flow rate, a display means for graphically and numerically displaying output data from the processor in real time, and a storage means for long term storage of output data from the computer in a format which can be processed at a later time.

The gas analyser typically comprises an electrochemical gas analyser as described in either of the US patent specifications 3 429 796 and 3 767 552, and a thermal conductivity sensor (which detects gas by comparing the thermal conductivity of the gas mixture with that of a pure background gas). Such a combination of analysers is particularly suited to the measurement of oxygen content and helium content of gas mixtures, and can readily determine the proportion of oxygen and helium in a mixture of helium, oxygen and nitrogen to produce representative electrical output signals. Since the base densities of pure helium, of pure oxygen, and of pure nitrogen are each known (at

standardized pressure and temperature), measurement of the oxygen content and the helium content, and the derivation of the nitrogen content of a mixture of said gases can be directly converted to a base density reading. Such a gas analyser is preferably calibrated against a gas mixture of known proportions. Alternatively the component sensors may be individually calibrated against samples of the relevant pure gas.

The mas flow meter preferably is a Coriolis force mass flow meter as described in GB patent specification 2 001 759, which is capable of directly measuring mass flow rate thorugh a conduit to produce a representative electrical output signal. Another Coriolis-type mass flow meter is described in US patent specification 4 691 578, and also this mass flow meter produces an electrical output signal which is representative of the mass flow rate of a gas flowing through a conduit.

The processor of the system according to the invention generally operates by dividing the mass flow rate measurement with the base density measurement to produce the desired standard volumetric flow rate measurement.

For measurement of actual flow rate there is used a unique formula to be described later, and an independent separate calculation is done.

Measurement of actual gas pressure and actual temperature can be performed by any suitable devices or equipment which may be an integral part of the gas analyser or separate therefrom.

A procedure for obtaining the volumetric flow rate at standardized conditions is to make the base density measurement under these standardized conditions. Thus, in the case where the gas analyser functions by analysing oxygen and helium content, gas samples can be obtained by bleeding a small but representative flow of gas mixture from the gas conduit through a pressure regulator or other pressure reducing device, and presenting the sampled gas to the gas analyser substantially at the standardized pressure, and at a temperature which does not differ from the standardized temperature by an amount which will produce significant errors in the resultant analytical measurements.

Measurement of volumetric flow can be converted to a measurement of total volume flow in a given period of time by

integration of the instantaneous volumetric flow rate measurements throughout that period of time. Integration of the appropriate electrical signals can be carried out by any suitable electronic circuit, either analogue or digital. Indication of total volumetric flow may be given both for actual volume, and for volume at the standardized pressure and temperature.

The invention will be further described below in connection with exemplary embodiments with reference to the accompanying drawings, wherein

Fig. 1 shows a schematic block diagram of an example of a gas flow measuring system for monitoring a gas mixture of helium, oxygen and nitrogen;

Fig. 2 shows a schematic block diagram of a first flow measuring apparatus used in the system in Fig. 1;

Fig. 3 shows a schematic electrical circuit of the system in Fig. 1;

Fig. 4 shows a typical screen of a display device in the system shown in Fig. 1; and

Figs. 5A-5D show data on screens appearing on the display device when depressing four of the functional keys shown in Fig. 4.

Fig. 1 is a highly schematic diagram showing functional blocks interconnected by gas conduits and electrical connections.

In Fig. 1, a supply system 10 for a breathing gas mixture for a diver is mounted on a ship or oil rig (not shown) and is coupled through a supply hose 12 and a return hose 14 to the helmet 16 of a diver 18. The breathing gas mixture is helium and oxygen, with between 2 and 21 volume percent of oxygen according to requirements. In normal operation, the system 10 is a closed loop breathing system in which the breathing gases are returned from the helmet 16 via the return hose 14 to a regenerator 20. Within the regenerator 20, carbon dioxide and other contaminants are removed from the exhaled gas by any suitable method, and either vented through a waste gas exhaust 22 or absorbed internally, in the case CO_2, in a container of soda lime (not shown). Since the oxygen content of the breathing gas is depleted by breathing, the proportion of oxygen is returned to the correct level by injection from an oxygen supply 24 through a control valve 26. The regenerator 20 preferably

also regulates the humidity of the regenerated breathing gas mixture at its output conduit 28. The temperature may additionally be regulated, though the required temperature for breathing is maintained locally at the diver by his heating system. Before the output of the regenerator 20 is fed back into the diver's closed loop breathing system, the regenerated gas mixture has its volumetric flow rate measured in a first gas flow measuring apparatus 30 shown in detail in Fig. 2, and which has a gas flow conduit 32 coupled to the closed loop breathing system. A gas analyser 34 is coupled to the gas flow conduit 32, to measure the oxygen and helium content of the breathing gas mixture in the closed loop breathing system, and to produce representative electrical output signals on an output signal lead 36.

The gas flow conduit 32 in the first measuring apparatus 30 is next coupled to a mass flow meter 38 which is preferably of the above-mentioned type according to GB patent 2 001 759, and which may be constituted by the commercially available "Micromotion"-range of mass flow meters and transmitters. In operation, the mas flow meter 38 produces a mass-flow-representative electrical output signal via an electronic transmitter (RFT 9712 in Fig. 2) on an output signal lead 40.

The continuation of the gas flow conduit 32 beyond the mass flow meter 38 conveys the gas mixture out of the first measuring apparatus 30 and into the closed loop breathing system.

Although the breathing system described above is nominally a closed loop system, there will in practice be a need to add gases to the system, either intermittently or continuously. This need arises from a number of causes, including leaks, deliberate venting or blowdown, and general increases in system pressure (for example due to descent of the diver 18). The make-up gases are supplied as required from a pressurized gas source 42 containing a helium/oxygen mixture of known proportions. Make-up gas supply from the gas source 42 is regulated by a control valve 44. For example if the diver 18 is operating at a depth of 100 metres at which the ambient water pressure is about 11 bar absolute, the pressure required at the inlet end of the supply hose 12 is about 28 bar, and the pressure of make-up gases in the gas flow conduit 38 will be maintained at the same pressure of 28 bar to match the pressure of the regenerated

breathing gas mixture in the gas flow conduit 32.

The volumetric flow rate of the make-up gases from the gas source 42 is measured by passing the make-up gases through a second gas flow measuring apparatus 46. This apparatus may be essentially similar to the gas flow measuring apparatus 30 as shown in Fig. 2.

The supply of make-up gases released through the control valve 44 enters a gas flow conduit 48 passing completely through the flow measuring apparatus 46. The gas flow conduit 48 first carries the make-up gases through a Coriolis-type mass flow meter 50 which is similar or identical to the mass flow meter 38. In operation, the mass flow meter 50 produces a mass-flow-representative electrical output signal on an output signal lead 52. The gas flow conduit 48 conveys the make-up gases from the mass flow meter to a gas analyser 54 which measures the oxygen content of the make-up gases to produce a representative electrical output signal on an output signal lead 56. The make-up gases then leave the second flow measuring apparatus 46 and enter the closed loop breathing system at a point immediately downstream of the first flow measuring apparatus 30 (which is delivering the regenerated breathing gas mixture to the inlet or surface end of the supply hose 12).

The output signal leads 36, 40, 52 and 56 are each connected to a digital processor 58 which may be a personal computer (PC). Prior to operational use, the supply system 10 will have been calibrated by supplying pure nitrogen (or a helium/oxygen/nitrogen mixture of known proportions) at a suitable known pressure and temperature to the gas analysers 34 and 54, to cause calibration measurements to be produced and fed to the processor 58 along the leads 36 and 56. The processor 58 is thereby enabled during operational use to convert the analogue oxygen and helium content measurement signals on the leads 36 and 56 to digital signals via an analogue-to-digital converter (see Fig. 3), and then convert the digital signals to equivalent base density measurement signals for the gas mixtures in the conduits 32 and 48, respectively.

The procedure for calculating the base density for the closed loop will be described later, after the following description of Figs. 2-4.

An embodiment of the gas flow measuring apparatus 30 in Fig. 1 is shown more in detail in Fig. 2. As mentioned above, the apparatus comprises a Coriolis-type mass flow meter 38 (type D 012) connected to an electronic transmitter 62 of the type RFT 9712. The transmitter supplies the mass-flow-representative signal to the processor 58 (Fig. 1) on the lead 40, and it also supplies a signal representative of the temperature of the gas mixture in the conduit 32 to the processor via a lead T. Further, a pressure sensor 64 and a transmitter 66 are coupled to the conduit 32, to supply a gas-pressure-representative signal to the processor via a lead P.

As shown, the gas analyser 34 comprises a oxygen analyser 68, e.g. of the type according to the above-mentioned US patents, and a helium thermal conductivity sensor 70. The oxygen analyser 68 is supplied with a suitable voltage through a regulated power supply 72 and a printed circuit board 72, whereas the helium sensor 70 is supplied with a suitable voltage via a printed circuit board 76. The circuit boards convert the voltage output signals from the analysers 68 and 70 to suitable current signals for transfer to the processor 58 via the leads 36.

The oxygen and helium analysers 68, 70 obtain an oxygen and helium content at approximately atmospheric pressure. This is accomplished by a pressure regulator 78 which first reduces the pressure of the gas from the conduit 32. An example of a suitable commercially available regulator is a "Tescom" regulator. The pressure-regulated gas flow from the regulator 78 is delivered along a conduit to a needle valve 80. The needle valve 80 is utilized to set the pressure regulator 78 to deliver an output pressure just above the ambient atmospheric pressure around the supply system 10. The gas passing through the needle valve 80 is delivered along an output conduit 82 to the oxygen analyser 68 and the helium analyser 70. Gases which have passed through the analysers 68, 70 are exhausted as waste gas to ambient through a vent 84. An additional conduit 86 is coupled to the conduit 82 in front of the oxygen analyser 68 and goes via a safety valve 88 to a vent 90.

As regards the flow measuring apparatus 46, this is, as mentioned, similar to the flow measuring apparatus 30 and may be

identical thereto, except that a helium analyser may be omitted as the make-up gas comprises only helium and oxygen, with no contaminants of significance, such as nitrogen present.

The electrical circuit diagram for the system 10 in Fig. 1 is schematically shown in Fig. 3 wherein parts correspon-ding to parts in Figs. 1 and 2 are designated by the same reference numerals.

The system is connected to mains voltage L,N,E through line volatage connectors 92, 94. As also shown in Fig. 2, the line voltage is supplied to the transmitter 62, the printed circuit board 76 and the power supply 72 for the units in the measuring apparatus 30 for the closed loop system. In a similar manner the line voltage is supplied to the units in the measuring apparatus 46 for the make-up gases, more specifically to a transmitter 96 (type RFT 9712) for the mass flow meter 50, and to a power supply 98 for the gas analyser 54 consisting of an oxygen sensor 100 and a printed circuit board 102 for vol-tage/current conversion. The line voltage is also supplied to an alarm unit 104.

In Fig. 3, the system processor 58 is shown to comprise the processor proper wich is constituted by a personal computer (PC) 106 and has an associated data storage means 107, and also the analogue/digital converter 108 of the system for converting the aforementioned analogue signals arriving through a cur-rent/voltage converter unit 110.

A main screen of the system's display device 60 (Fig. 1) is shown in Fig. 4 and shows typical information displayed on the screen. As appears from the Figure, the screen is divided into four upper fields showing "date", "real time", "elapsed time" and "diving bell depth" for the dive operation in question, and thereunder a number of fields which numerically as well as graphically show "gas flow to diver", "make-up gas flow" and "average efficiency", and in addition numerical values of "standardized gas flow" (m^3/min.) and "total gas flow" (m^3) both for the flow to the diver and the make-up gas flow, together with values of "actual flow" and "average efficiency". Therebelow there are various "alarm windows" and other information, such as "diving bell pressurization" and "cross connection".

At the bottom of the display device there are arranged

a number of functional keys, more specifically seven keys (F1-F7) designated by the reference numerals 111-117. The first six keys have the designations "Accept", "Alarm status", "Event file", "Edit alarm", "Dive data" and "Review disk", whereas the seventh key 117 is unoccupied (without designation). When depressing the various keys, a corresponding screen appears on the display device. Examples of the "content" of the keys F3-F6 are shown in Figs. 5A-5D.

In accordance with the software which has been prepared for the system processor/computer, there may be produced, by suitable key-entries, other or additional screens showing desired operational data in connection with topical system operations.

The data produced by the processor and displayed on the display device, will also be permanently stored in a suitable storage means, advantageously on diskettes, with a view to subsequent processing and utilization, possibly in connection with later operations. In this manner an efficient facility is obtained, both for control and for efficient operational management.

In order to calculate the base density for the closed loop, the percentage by volume of nitrogen N_2 is derived by means of the equation

$$\%N_2 = 100\% - \%O_2 - \%He,$$

the percentages by volume of oxygen and helium being obtained from the analysers 68 and 70.

From this the base density for the closed loop can be calculated as follows:

$$XjHe \cdot jHe + XjO_2 \cdot jO_2 + XjN_2 \cdot jN_2,$$

where X = composition (mole fraction) % by volume of each individual gas,

and where

$jHe = 0.1786$

$jO_2 = 1.4276$

$jN_2 = 1.2498$

these figures being the system constants or ideal densities of the gases (molar mass/molar volume of an ideal gas at 0°C and 1.013 bar),

and wh re

$XjHe = $ % He by volume

XjO_2 = % O_2 by volume

XjN_2 = % N_2 by volume

For the make-up gas only one analyser is used as only oxygen and helium are present. The base density is calculated as follows:

$$XjHe \cdot jHe + XjO_2 \cdot jO_2$$

where the symbols have the same meaning as before except that in this case they are for the make-up gas flow.

The processor 58 also receives direct mass flow rate measurements via the leads 40 and 52 from the mass flow meters 38 and 50, respectively. By dividing the direct mass flow rate readings by the calculated base densities the processor 58 can calculate the respective standard volumetric flow rates in the gas flow conduits 38 and 40, and thus the flow rate of the mixed gas entering the supply hose 12. As mentioned above, these standard volumetric flow rates can be individually or collectively indicated on the display device 60 adjacent to the processor 58, but they can also be indicated at a separate dive control station (not shown). From the measurements the processor 58 can also calculate the efficiency of the regenerator 20 and display this on the display device 60 to show the trend over a time.

The pressure and temperature measurements mentioned in connection with Fig. 2 may be taken by suitable transducers either incorporated in the gas analysers 34 and 54 or otherwise respectively coupled to the gas flow conduits 32 and 48, to feed respective measurements to the processor 58 (via the leads P and T). Such pressure and temperature measurements enables the processor 58 to perform an independent calculation of the actual volumetric flow rate by using the unique formula stated below:

$$A_f(1/min) = \frac{Q_M \times 83.14 \times [T_c+273] \times [1 + (0.00074 \times P_2)]}{P_2 \times M_{Wc}}$$

where

A_f = Actual flow in litres per min.

Q_M = Mass flow in kg per min.

P_2 = Line or gauge pressure in bar

T_c = Line temperature in °C

M_{wc} = Calculated molecular weight of gas mixture

A first principle explanation of the development of the above-mentioned formula is given in Appendix A.

As mentioned in connection with Fig. 4, standard volumetric flow rates can be displayed in addition to or as an alternative to displaying the actual volumetric flow rates.

The processor 58 preferably performs a time integration of the volumetric flow rate measurements (whether actual, standardized, or both) to give total volumetric flow over the period of integration, respectively expressed as actual volume, standardized volume, or both.

The processor 58 preferably correlates the various measurements of volumetric flow rates and volumetric flows to give indications of the performances of the various parts of the system 10 and the diver 18, and in addition indications of possible or actual leaks from any part of the system 10, the hoses 12 and 14, and the diver's helmet 16. (The performance of the diver can be monitored by measurements of his breathing gas consumption, which is closely related to his rate of physical exertion, while a high or low breathing gas consumption may indicate a medical emergency.) An abnormally high flow of make-up gases from the source 42 usually indicates an unacceptably serious leak (providing the system has not indicated a "Cross connection" or "Blowdown"/"Bell pressurization" - see Fig. 4).

The system of Fig. 1 has been described in connection with monitoring of the supply and consumption of a diver's breathing gas mixture during diving operations. However, the gas flow measuring system according to the invention is not restricted to such application, and a number of other uses are possible. As examples there may be mentioned (1) monitoring the regeneration and purification of spent breathing gases after a diving operation is concluded, such as when the gases are being purified by a process not employed during diving operations, e.g. to remove metabolites other than carbon dioxide; (2) accurate volumetric measurement of the delivery of bulk supplies of gases from a gas manufacturer/supplier; (3) monitoring the volumetric flow rates of oxygen-enriched air employed for medical or therapeutic purposes, as in hyperbaric oxygen therapy or to aid the breathing of hospital patients at atmospheric pressure;

(4) monitoring the volumetric flow rates of anaesthetic/analgesic gas mixtures, whether in closed-loop breathing systems or in open-loop breathing systems; and (5) monitoring the volumetric flow rates of gas mixtures employed for industrial purposes, e.g. in chemical engineering or in carburation.

The invention therefore provides a device which will measure flow rates of gases in volumetric terms, express the readings in standard or actual form, e.g. standard m^3 per minute, and show the total flow, e.g. standard m^3, wherein "standard" is the volume that the gas would occupy under standard conditions of temperature and pressure (0°C and 1.013 bar).

APPENDIX A

Calculation of actual flow

In the formula development the follwing abbreviations are used:

A_f = Actual flow in litres per min.

Q_M = Mass flow in kg per min.

P_1 = Line pressure in Pascal

P_2 = Line pressure in bar

R = Universal gas constant

M_w = Molecular weight

M_{wc} = Calculated molecular weight of gas mixture

T = Line temperature in K

T_c = Line temperature in °C

Z = Compressibility factor

D_L = Line density

% = Percentage by volume

Formula component development

M_{Wc}

As the molecular masses of helium, oxygen and nitrogen are respectively 4.0026, 31.9988 and 28.0134, the calculated molecular weight of the gas mixture may be written as follows:

$$M_{Wc} = [\%O_2 \times 32] + [\%He \times 4] + [\%N_2 \times 28]$$

R

From the value of the molar gas constant, the universal gas constant R may be written as follows:

$$R = \frac{8314.34}{M_{Wc}}$$

Z

For a gas mixture consisting of helium, oxygen and nitrogen with 79-100 % by volume of helium, 0-21 % by volume of oxygen and 0-5 % by volume nitrogen, it can be shown empirically over a range of pressures from 0 to 100 bar that the compressibility factor of the gas mixture is equal to

$$[1 + (0.00074 \times P_2)]$$

where P_2 is the line pressure in bar.

D_L (line density in kg/m^3)

The line density is calculated using the Gas Law formula

$$P_1/(R \times T \times Z),$$

where P_1 = Line pressure in Pascal (e.g. bar x 10^5)
R = Universal gas constant
T = Line temperatur in K
Z = Compressibility factor

Q_M

The value of Q_M is read directly in kg/min. from the "Micro-motion" mass flow meter connected in the line.

Development of formula

$$\text{Actual flow} = \frac{\text{Mass}}{\text{Density}} \text{ in } m^3 \text{ per min.}$$

$$= \frac{\text{Mass}}{P_1/(R \times T \times Z)} = \frac{\text{Mass} \times (R \times T \times Z)}{P_1}$$

$$= \frac{\text{Mass} \times [8314.34/M_{Wc}] \times [T_c + 273] \times [1 + (0.00074 \times P_2)]}{P_2 \times 10^5}$$

$$A_f(1/\text{min}) = \frac{Q_M \times 8314.34 \times 10^3 \times [T_c+273] \times [1 + (0.00074 \times P_2)]}{P_2 \times M_{Wc} \times 10^5}$$

$$= \frac{Q_M \times 83.14 \times [T_c+273] \times [1 + (0.00074 \times P_2)]}{P_2 \times M_{Wc}}$$

It is to be noted that the finished formula for software accepts pressure in bar and temperature in °C and gives the actual flow A_f in litres per minute, which is the definition of r.m.v. (respiratory minute volume).

Patent claims

1. A gas flow measuring system comprising a gas flow conduit for carrying a gas mixture of known constituents in unknown proportions, a gas analyser (34) coupled to the conduit and generating analogue signals representative of the unknown proportions of the gas mixture, a mass flow meter (38) coupled to the conduit and generating an analogue signal representative of the mass flow rate of the gas mixture, and a means (58) for processing said signals to produce at least a signal representative of the volumetric flow rate of the gas mixture, CHARACTERIZED IN that it includes a converter (108) for conversion of said analogue signals to digital signals, a digital processor (58) for processing the digital signals from the converter, to produce output data representative of, i.a., said volumetric flow rate, a display means (60) for graphically and numerically displaying output data from the processor (58) in real time, and a storage means (107) for long term storage of output data from the computer in a format which can be processed at a later time.

2. A system according to claim 1, CHARACTERIZED IN that it includes sensors for sensing of the pressure and temperature of the gas mixture in the gas flow conduit, and that the processor (58) is arranged to calculate the actual volumetric flow rate of the gas mixture by means of the formula:

$$A_f(\mathrm{l/min}) = \frac{Q_M \times 83.14 \times [T_c+273] \times [1 +(0.00074 \times P_2)]}{P_2 \times M_{Wc}}$$

where

A_f = Actual flow in litres per min.

Q_M = Mass flow in kg per min.

T_c = Line temperature in °C

P_2 = Line pressure in bar

M_{Wc} = Calculated molecular weight of gas mixture.

3. A system according to claim 1 or 2, wherein the gas mixture is a ternary breathing gas mixture comprising oxygen, helium an nitrogen circulating in a closed loop breathing system, and a gas mixture consisting of oxygen and helium is supplied to the closed loop as make-up gas, and wherein the system is in duplicated design with respect to gas analyser and mass flow

meter, for volumetric flow measurement both of the gas mixture in the closed loop syst m and the gas mixture supplied as make-up gas, CHARACTERIZED IN that the gas analyser (34) in the closed loop system comprises an O_2 sensor (68) and a He sensor (70), the processor (58) being arranged to calculate the remaining N_2 proportion on the basis of the signals from said sensors, whereas the gas analyser (54) for the make-up gas comprises only an O_2 sensor (100), the processor being arranged to calculate the He proportion on the basis of the signal from the O_2 sensor.

4. A system according to any of the claims 1-3, CHARACTERIZED IN that the display means (60) is provided with a number of functional keys (111-117) cooperating with the processor (58) and causing, when selectively depressed, the processor to display a screen on the display means (60) showing special operational data which are connected to said key.

5. A system according to claim 4 in dependence on claim 3, CHARACTERIZED IN that the functional keys (111-117) are arranged to produce respective screens representing for example "Event file", "Dive data", "Alarm settings".

6. A system according to any of the preceding claims, CHARACTERIZED IN that the processor is a personal computer (106) and that the storage means (107) consists of diskettes.

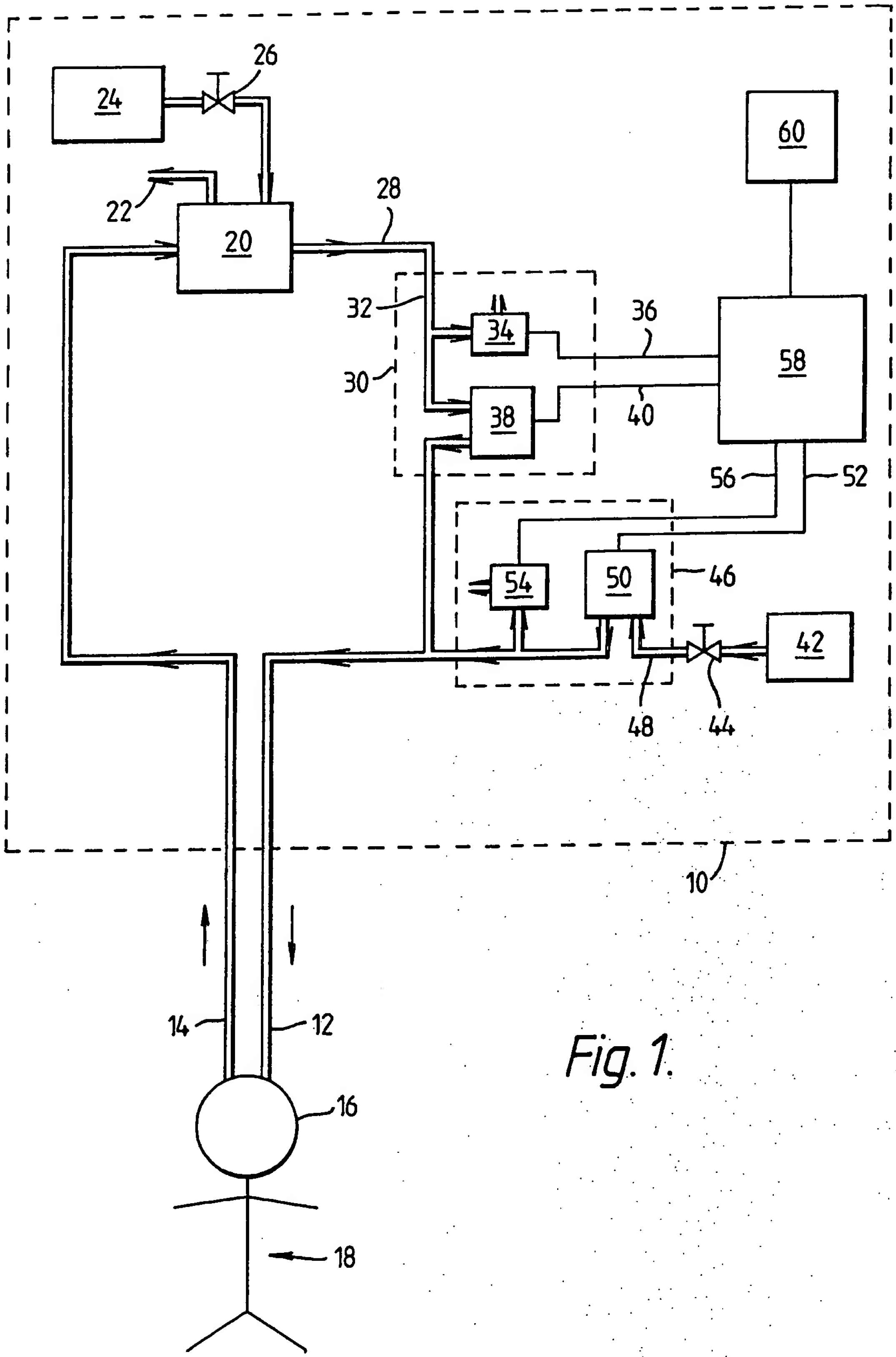

24
26
60
22
20
28
32
34
36
58
30
38
40
56
52
54
50
46
42
48
44
10
14
12
16
18

Fig. 1.

Fig. 2.

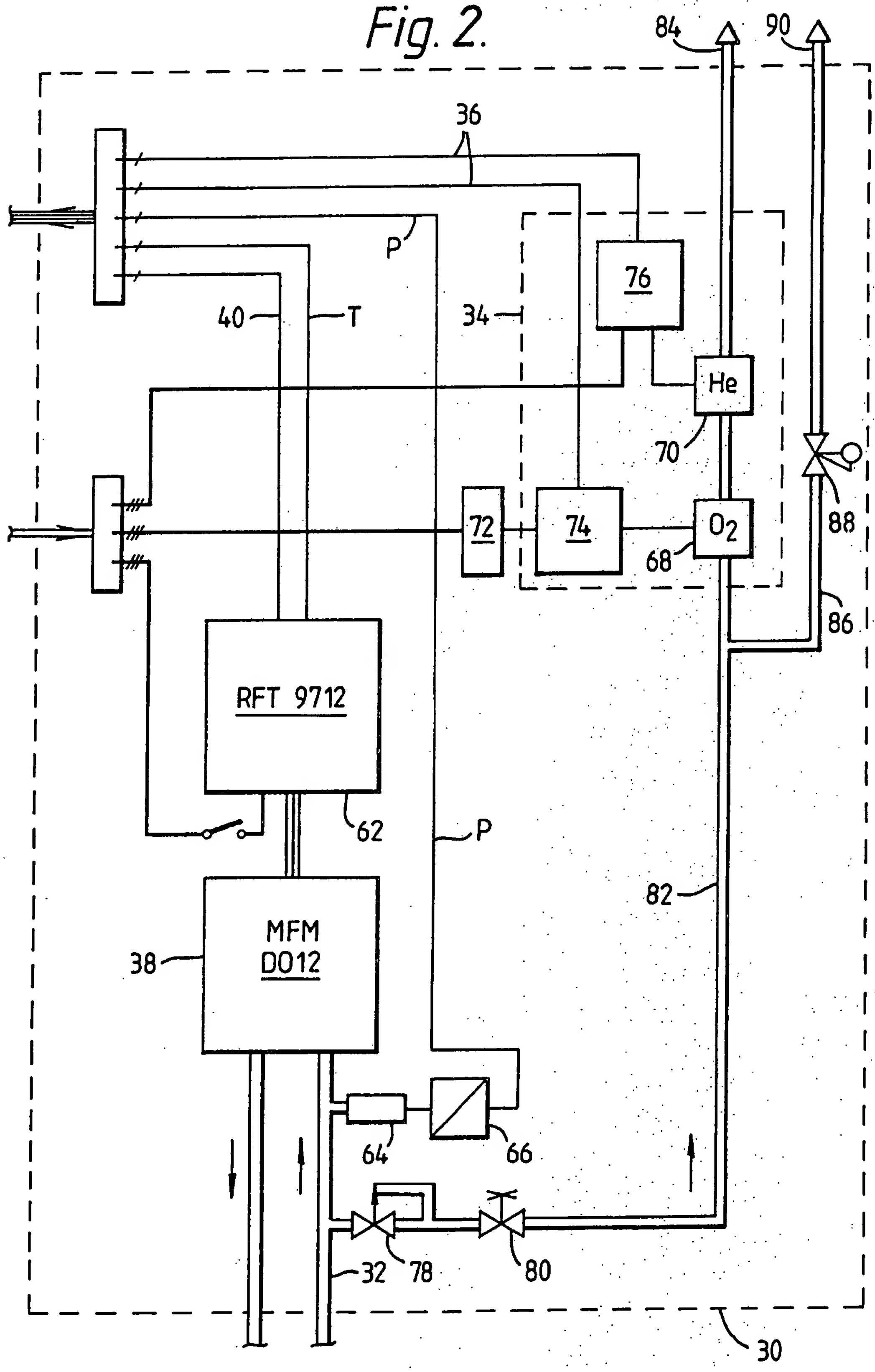
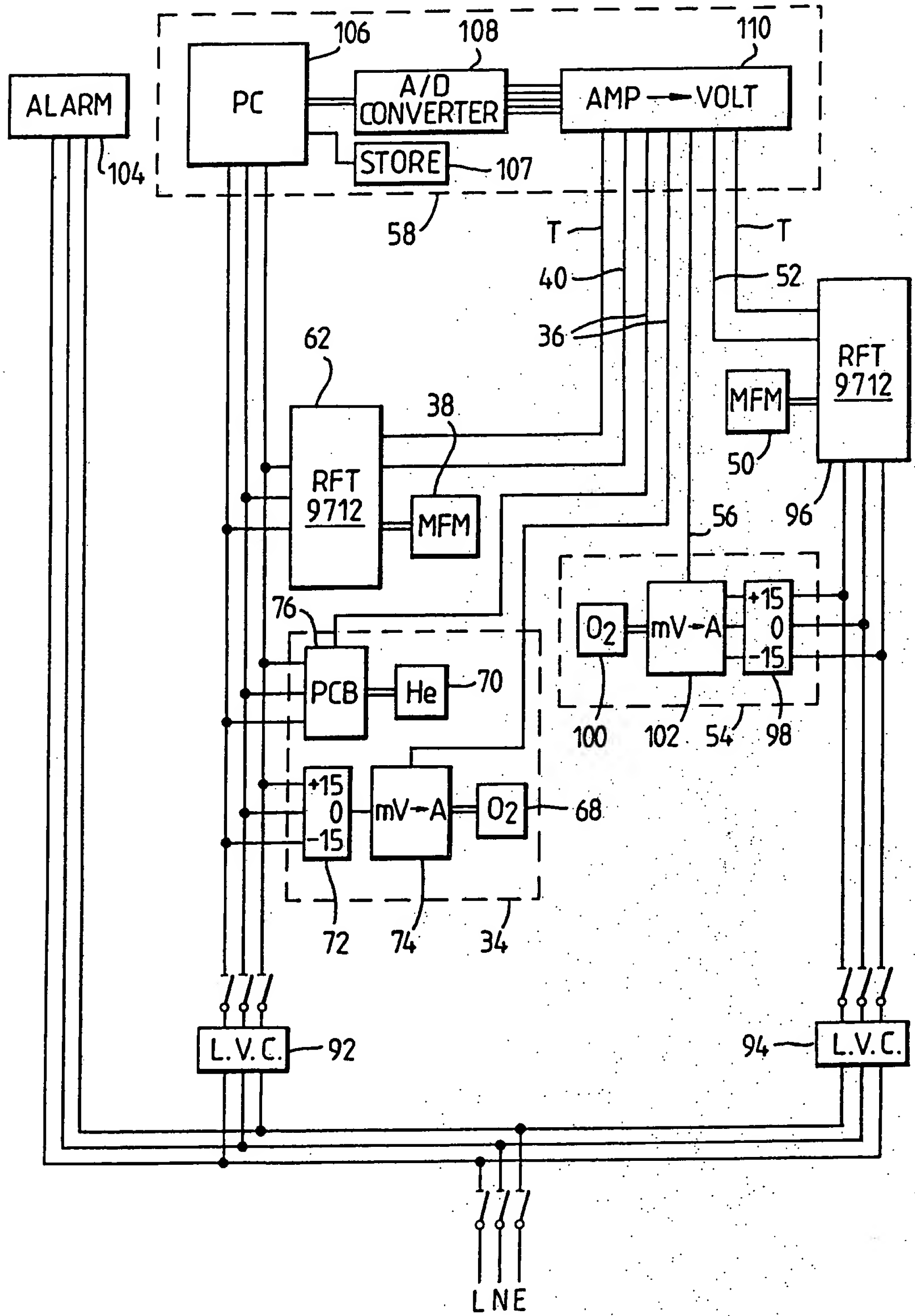

84
90
36
P
76
40
T
34
He
70
88
72
74
O2
68
86
RFT 9712
62
P
82
MFM
DO12
38
64
66
32
78
80
30

Fig. 3.



ALARM
PC
A/D CONVERTER
AMP → VOLT
STORE
106
108
110
104
107
58
T
T
40
52
36
62
38
RFT 9712
MFM
RFT 9712
MFM
50
56
96
76
PCB
He
70
O2
mV→A
+15 0 −15
100
102
54
98
+15 0 −15
mV→A
O2
68
72
74
34
L.V.C.
92
94
L.V.C.
L N E

Fig.4.

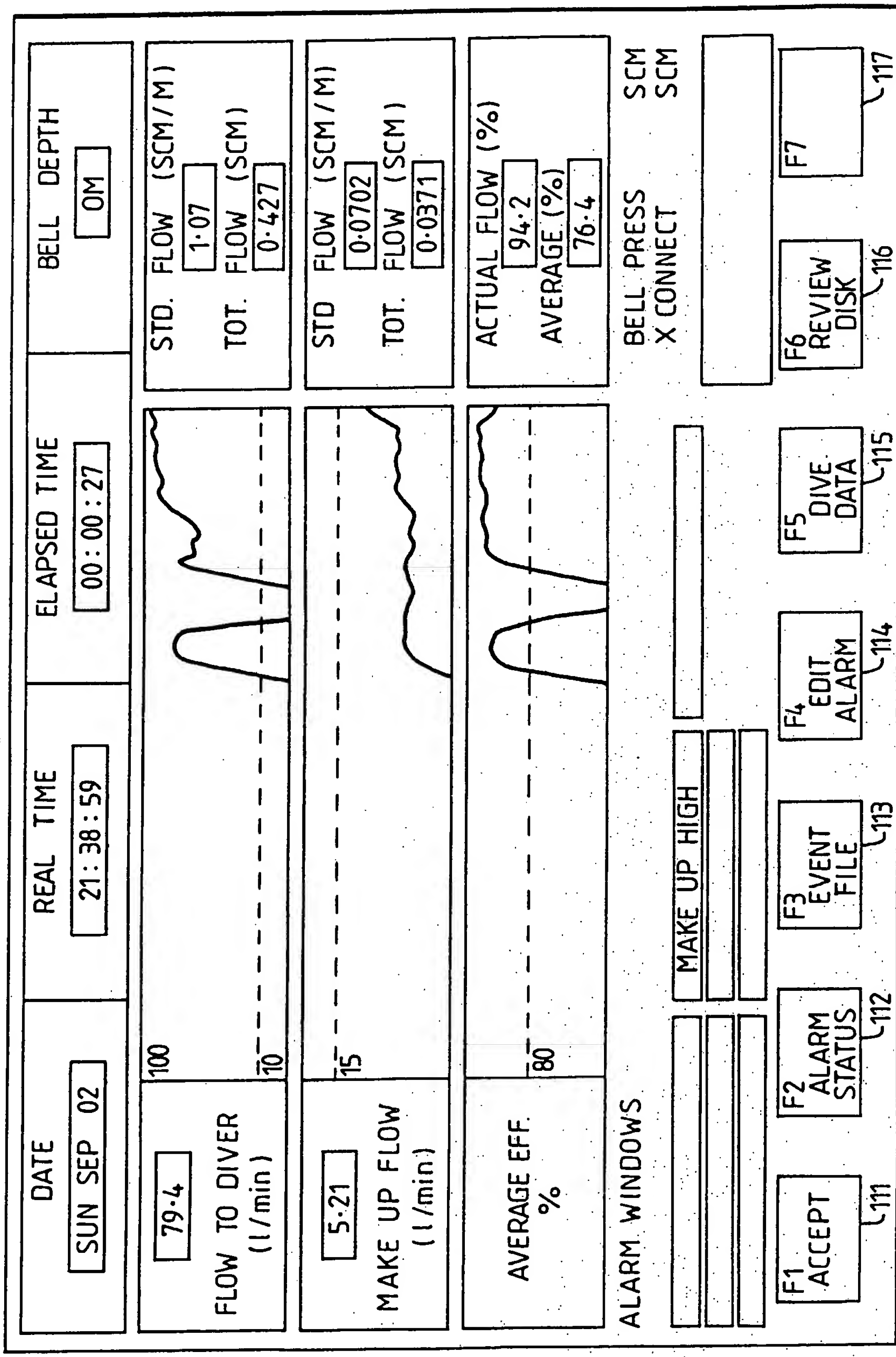

DATE
SUN SEP 02
REAL TIME
21:38:59
ELAPSED TIME
00:00:27
BELL DEPTH
0M
79·4
FLOW TO DIVER
(l/min)
100
10
STD. FLOW (SCM/M)
1·07
TOT. FLOW (SCM)
0·427
5·21
MAKE UP FLOW
(l/min)
15
STD FLOW (SCM/M)
0·0702
TOT. FLOW (SCM)
0·0371
AVERAGE EFF.
%
80
ACTUAL FLOW (%)
94·2
AVERAGE (%)
76·4
ALARM WINDOWS
MAKE UP HIGH
BELL PRESS SCM
X CONNECT SCM
F1 ACCEPT
111
F2 ALARM STATUS
112
F3 EVENT FILE
113
F4 EDIT ALARM
114
F5 DIVE DATA
115
F6 REVIEW DISK
116
F7
117

Fig. 5A

F3

EVENT FILE

NO	EVENT
0	START LOG (NON ADJUSTABLE)
1	DIVERS IN BELL
2	BELL LEAVES SURFACE
3	BELL ON BOTTOM
4	BELL DOOR OPEN
5	DIVER 1 LEAVES BELL
6	DIVER 2 LEAVES BELL
7	DIVER 1 ARRIVES WORKSITE
8	DIVER 2 ARRIVES WORKSITE
9	DIVER 1 LEAVES WORKSITE
10	DIVER 2 LEAVES WORKSITE
11	DIVER 1 ENTERS BELL
12	DIVER 2 ENTERS BELL
13	BELL DOOR CLOSED
14	BELL LEAVES BOTTOM
15	BELL ON SURFACE
16	BELL MATED
17	DIVERS LEAVE BELL
⋮	
30	STOP LOG (NON ADJUSTABLE)

EDIT FILE | PRINT FILE | RETURN

Fig. 5B

F4

ALARM SETTINGS

No.	DISPLAY	SETPOINT HIGH	SETPOINT LOW
1	FLOW TO DIVER (1/min)	100%	0
2	MAKE-UP FLOW (1/min)	50%	N/A
3	PERCENT EFFICIENCY	N/A	70%

EDIT FILE

RETURN

Fig.5C

F5

DIVE DATA

VESSEL NAME	:	B.P. IOLAIR
LOCATION	:	FORTES ALPHA
JOB DESCRIPTION	:	JACKET CLEANING
DIVE	:	24 MAY 1989
TIME	:	16:32:20
DIVE NUMBER	:	12
BELL DEPTH (MSW)	:	85
DIVERS LOCKED OUT	:	2
DIVE SUPERVISOR	:	A. N. OTHER
DIVER 1	:	J.SMITH
DIVER 2	:	H.BLOGGS
BELLMAN	:	S BROWN

EDIT FILE

RETURN

Fig. 5D

F6

REVIEW DISK

1. DIVE DATA

.

.

PRINTS FILE INPUT TO DISK AT F5

.

.

2. DIVE LOG

REAL TIME	ELAPSED TIME	EVENT
:	00:10:10	DIVERS IN BELL
:	00:17:30	BELL LEAVES SURFACE
:	:	BELL ON BOTTOM
:	:	BELL DOOR OPEN
:	:	DIVER 1 LEAVES BELL
:	:	DIVER 1 ARRIVES WORKSITE
:	:	DIVER 2 LEAVES BELL
:	:	DIVER 2 ARRIVES WORKSITE
:	:	LOW RECLAIM EFFY. ALARM ON
:	:	LOW RECLAIM EFFY. ALARM OFF
:	:	DIVER 1 LEAVES WORKSITE
:	:	DIVER 2 LEAVES WORKSITE
:	:	DIVER 1 ENTERS BELL
:	:	DIVER 2 ENTERS BELL
:	:	BELL DOOR CLOSED
:	:	BELL LEAVES BOTTOM
:	:	BELL ON SURFACE
:	:	BELL MATES
:	:	DIVERS LEAVES BELL

Cont.

Fig. 5D (cont.)

F6

REVIEW DISK Cont.

3. RECLAIM SYSTEM DATA

TOTAL GAS SUPPLIED TO DIVER	=	SCF
TOTAL MAKE-UP GAS USED	=	SCF
AVERAGE SYSTEM EFFICIENCY	=	%
GAS USED FOR BELL PRESSURISATION	=	SCF
GAS FLOWED WITH X-CONNECT OPEN	=	SCF
AVERAGE ACTUAL DIVER FLOW RATE	=	act.1/min

4. ALARM SETPOINTS

PRINTS CONTENTS INPUT AT F4

PRINT

RETURN

INTERNATIONAL SEARCH REPORT

International Application No PCT/NO 90/00161

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC5: G 01 F 1/74, B 63 C 11/24, A 61 M 16/00

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
IPC5	G 01 F, B 63 C, A 61 M

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in Fields Searched[8]

SE,DK,FI,NO classes as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category *	Citation of Document,[11] with indication, where appropriate, of the relevant passages[12]	Relevant to Claim No.[13]
Y	EP, A, 0274868 (CLAUSEN, KALDAGER INSTRUMENTS LIMITED) 20 July 1988, see abstract --	1-6
Y	EP, A, 0278671 (ANADRILL INTERNATIONAL SA) 17 August 1988, see abstract; figure 2 --	1
Y	EP, A, 0324259 (W.D. BUDINGER) 19 July 1989, see column 14, line 43 - line 50; figure 1 --	1,3
A	FR, A, 2615163 (H. BOVY ET AL) 18 November 1988, see page 3, line 20 - line 29 --	1-6

* Special categories of cited documents:[10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance, the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance, the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
4th February 1991	1991 -02- 06
International Searching Authority	**Signature of Authorized Officer**
SWEDISH PATENT OFFICE	Harriet Ekdahl HARRIET EKDAHL

Form PCT/ISA/210 (second sheet) (January 1985)

International Application No. PCT/NO 90/00161

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
Y	US, A, 4353118 (H. HEIMGARTNER ET AL) 5 October 1982, see abstract; figures 1,3 --	1,4
A	US, A, 4519257 (O.K. SIMPKINS) 28 May 1985, see figure 5 --	1-6
Y	US, A, 4783750 (D.W. SMITH) 8 November 1988, see column 4, line 47 - line 63; figure 1 -- --------	1-6

ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO. PCT/NO 90/00161

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the Swedish Patent Office EDP file on 90-12-28
The Swedish Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A- 0274868	88-07-20	AU-D- 1040988	88-06-30
		EP-A- 0274246	88-07-13
		WO-A- 88/04409	88-06-16
EP-A- 0278671	88-08-17	US-A- 4754641	88-07-05
EP-A- 0324259	89-07-19	AU-D- 2732688	89-07-13
		JP-A- 2141389	90-05-30
		US-A- 4876903	89-10-31
		US-A- 4926703	90-05-22
FR-A- 2615163	88-11-18	NONE	
US-A- 4353118	82-10-05	EP-A- 0024488	81-03-11
US-A- 4519257	85-05-28	NONE	
US-A- 4783750	88-11-08	CA-A- 1251279	89-03-14
		FR-A- 2598834	87-11-20
		GB-A-B- 2194045	88-02-24